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CHAPTER XVIII.

TEACHING OF ASTRONOMY.

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CHAPTER XVIII.

THE TEACHING OF ASTRONOMY IN THE PRIMARY AND SECONDARY SCHOOLS AND IN THE UNIVERSITY.

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I. THE TEACHING OF ASTRONOMY IN THE PRIMARY SCHOOLS.

The earliest teaching of astronomy must be closely joined to the teaching of geography. What is already known about the earth will serve as a stepping-stone to a knowledge of the planets. Conversely, the little that is known of the planets serves to throw light upon the constitution of the earth, and especially upon its past and future history. Any child old enough to study geography is not too young to begin to observe simple astronomical phenomena and to grasp astronomical ideas. Prof. Edward Gardnier Howe, in his Manual of Systematic Science Teaching,[1] has given a useful and intelligent scheme according to which astronomy may be taught during the early years of a child's school life. Reference should be made to this scheme by teachers of science in the primary schools, although it ought not by any means to be followed slavishly.

The lessons of the first years are necessarily extremely simple. The child must first be led to make an inventory of the visible universe—sun, moon, and stars. Among the stars the brighter planets (Venus, Mars, Jupiter) may be pointed out; and it will be easy to direct attention to the constellations—the Great Bear (the Dipper), Orion, the Pleiades. During the whole school life of the child the naming of the constellations may go on. It is not necessary to learn the designations of any of the fainter stars, nor even the names of more than a dozen of the bright ones. But it is desirable that the names of the principal constellations should be associated with the star groups. A very little time given to this matter will do wonders. A child's fresh memory is readily impressed. A few of the stars which are closely double to the naked eye (Epsilon Lyræ, etc.) may be pointed out, as well as the nebula of Andromeda and the star clusters of Scorpio and the Præsepe. The course of the Milky Way must be traced and the Zodiacal Light rediscovered.

Very many children will take a lively interest in the identification of stars (and planets), and a clever teacher can inspire them to do such work on their own account, and at home. The delight of discovery is hardly less poignant to the child who has really observed for the first time that the stars in their courses move from east to west, or that the planets really move among the stars, than to an astronomer who makes some real step to advance his science.

Early in the child's life the study of the moon's face and of her motions should be commenced. There is really no end to it during the whole of the pupil's school life. After the unassisted eye has done its part the use of a common field glass opens a new world. Galileo was not better equipped. The opera glass, a watch,

[1] International Education Series, Vol. XXVII, 1894.

a compass, a straight stick for a gnomon, or for testing the allineations of stars (or planets); bits of colored glass for looking at the sun (care must be exercised in this matter); a terrestial and a celestial globe—if possible a blank slate globe on which drawings can be made with chalk; a rude sundial, which can be made by the pupils themselves (not by theory, but by making its indications agree approximately with those of a watch); possibly a simple spyglass on a firm support, or at least a straight pointer or stick mounted like an equatorial; these are the pieces of apparatus which should be successively utilized by the teacher. It is very important to introduce these aids slowly and one by one. The eye should be faithfully employed before the opera glass is used. Thoroughness is a scientific (and a moral) virtue which the child may begin to learn from his earliest days; and these simple beginnings of astronomical acquirement can be used to impress the habit on the pupil.

The observation of the morning and evening stars will serve as an introduction to the mapping of the apparent path of a planet among the stars, and the revolutions of the moon will suggest the origin of the month, and thus introduce some consideration of the calendar—a knotty subject. The child who lives on the seacoast may already know something of the tides. The nature of solar time and its relation to sidereal time can be introduced with the study of the sun's motions. The apparent motions of the moon and planets lead to investigations of the real motions of both planets and earth. Spherical bodies are illuminated in a special manner by the central sun, and cast shadows of a particular size and shape. Thus eclipses may occur, and the conditions for an eclipse may be perfectly well comprehended, even by young pupils. A school experiment on a sunny day, with two globes and with a smoky atmosphere (artificially produced) in the room, will exhibit the essentials of the phenomenon. Latitude, longitude, time, pendulum clocks, telescopes, the sun's heat received by the earth, the seasons, twilight, etc., may be taken up in order, as occasion serves.

Everything depends on the teacher. It is essential that he should thoroughly understand the subject if he is to present it vividly to young minds. It is important that the children should be given ample time to grasp novel doctrines and not be hurried. At the same time it is almost equally essential that they should be led onward and not merely revolve for days about a single topic. Nothing exhibits the skill of an instructor more convincingly than his power to display a given subject in many and various lights. A topic that has been thoroughly studied in one aspect gains a new freshness and interest by a presentation from a novel point of view. The power of conceiving in the sky the circles of the sphere—the meridian, the equator, the ecliptic—must be steadily cultivated. The circles exist first of all in the heavens, and the text-book or the school globe only exists because the circles are there. The ground idea of an eclipse is very simple if it is studied out of doors by experiments with real shadows. Afterwards the drawings in the text-books become intelligible. The power to conceive geometric relations of the sort can be wonderfully cultivated even in young children. Just as descriptive geometry gives the very best training to more advanced students of mathematical form, so this habit of representing geometric relations in the mind is of prime importance to the beginner.

No special consideration of the manner of instructing children of the primary grades in astronomy need be given here. The teaching should, in general, be directed chiefly to training their eyes and mind to observation of natural phenomena rather than to instruction in the elements of the particular science of astronomy. What they learn of astronomy is of comparatively little account. The real matter is to use the solar system so as to train each small mind to observe, register, and reflect. Later on, in the secondary schools, astronomy may be studied not only for its educative effect, but also as an information-study. In the general college courses its chief value is to give an idea of the methods of this particular science, and thus of all science.

For primary pupils the main point is to open the eyes and mind, and the sun and stars are convenient for the purpose. A detailed scheme for such instruction during the earliest years of the school life of the child is given in the book of Professor Howe, already mentioned. This programme, modified as necessary and convenient, will serve as a guide to the teacher of primary pupils in astronomy. The manner of teaching this science in secondary schools and in colleges will next be treated with all necessary fullness.

II. TEACHING OF ASTRONOMY IN THE SECONDARY SCHOOLS.

The committee on secondary school studies, which was appointed at the meeting of the National Educational Association in 1892, considered the whole question of high-school courses of study and made a report,[1] whose conclusions have been accepted on nearly all hands as satisfactory, and in the present state of instruction in the country as final. With a better instructed force of teachers we may look for higher requirements. The committee (known as the Committee of Ten) was composed of the president of Harvard University, the United States Commissioner of Education, the president of the University of Michigan, the headmaster of the Girls' High School of Boston, the president of Vassar College, the principal of the High School of Albany, the president of the University of Colorado, the president of the University of Missouri, the headmaster of the Lawrenceville School of New Jersey, and a professor of Oberlin College. It was thus representative of the whole country geographically, and of the best in the country pedagogically. The Committee of Ten was aided in its work by nine other committees ("conferences"), each composed of ten experts.

The conferences considered the following studies or groups of studies: (1) Latin; (2) Greek; (3) English; (4) other modern languages; (5) mathematics; (6) physics, astronomy, and chemistry; (7) natural history (biology, including botany, zoölogy, and physiology); (8) history, civil government, and political economy; (9) geography (physical geography, geology, and meteorology). The ninety members of the conferences were divided as follows: Forty-seven were in the service of colleges or universities, forty-two were in the service of schools. Many of the men in the service of the colleges had had previous service in schools. The discussions of the several conferences were "frank, earnest, and thorough," but "in every conference an extraordinary unity of opinion was arrived at." "The unanimity developed is very striking and should carry great weight." The conference reports were comprehensively discussed by the Committee of Ten and "a cordial agreement as to both the form and substance" of the printed report just cited was arrived at.[2]

These facts, which will be in the memories of most of the readers of this chapter, are here set down in order to emphasize the authoritative nature of the report of the Committee of Ten. Their conclusions, as hereafter quoted, must be taken as carrying the greatest weight. A differing judgment will require to be fully discussed.

The following paragraphs from the report of the Committee of Ten are quoted here for convenience of reference:

> Anyone who reads these nine reports [of the conferences] consecutively will be struck with the fact that all these bodies of experts desire to have the elements of their subjects taught earlier than they now are, and that the conferences on all the subjects, except the languages, desire to have given in the elementary schools

[1] Publications of the United States Bureau of Education, No. 205, 1893.

[2] With a very few exceptions printed in a minority report from the president of the University of Colorado.

what may be called perspective views or broad surveys of their respective subjects, expecting that in later years of the school course parts of these same subjects will be taken up with more amplitude and detail. * * * The conference on physics, chemistry, and astronomy urge that nature studies should constitute an important part of the elementary school course from the very beginning. * * *

Finally, the conference on geography recommend that the earlier course treat broadly of the earth, its environment and inhabitants, extending freely into fields which in later years of study are recognized as belonging to separate sciences.

* * * * * * *

In thus claiming entrance for their subjects into the earlier years of school attendance, the conferences are only seeking an advantage which the oldest subjects [language, arithmetic, geography] have long possessed. * * * As things now are, the high-school teacher finds in the pupils fresh from the grammar schools no foundation of elementary mathematical conceptions outside of arithmetic, no acquaintance with algebraic language, and no accurate knowledge of geometrical forms. As to [physics, astronomy, etc.] the minds of pupils entering the high school are ordinarily a blank. When college professors endeavor to teach [astronomy] to persons of 18 or 20 years of age they discover that in most instances new habits of observing, reflecting, and recording have to be painfully acquired by the students—habits which they should have acquired in early childhood. The college teacher * * * finds that his subject has never taken any serious hold on the minds of pupils fresh from the secondary schools. * * * It is inevitable, therefore, that specialists in any one of the subjects which are pursued in the high schools or colleges should earnestly desire that the minds of young children be stored with some of the elementary facts and principles of their subject, and that all the mental habits, which the adult student will surely need, begin to be formed in the child's mind before the age of 14. * * * The changes recommended are all in the direction of increasing simultaneously the interest and the substantial training quality of primary and grammar school studies. * * *

On one very important question of general policy * * * the committee of ten and all the conferences are absolutely unanimous. * * * Ninety-eight teachers, intimately concerned either with the actual work of American secondary schools, or with the results of that work as they appear in students who come to college, unanimously declare that every subject which is taught at all in a secondary school should be taught in the same way and to the same extent to every pupil so long as he pursues it, no matter what the probable destination of the pupil may be, or at what point his education is to cease. * * * Not that all the students should pursue every subject for the same number of years; but so long as they do pursue it, they should all be treated alike.

All the conferences on scientific subjects dwell on laboratory work by the pupils as the best means of instruction * * * and they all protest that teachers of science need at least as thorough a special training as teachers of languages. * * *

SUMMARY OF THE REPORT OF THE CONFERENCE ON PHYSICS, CHEMISTRY, AND ASTRONOMY.

The conference was urgent that the study of simple natural phenomena be introduced into elementary schools. * * * Apparently the conference entertained the opinion that the present teachers in elementary schools are ill-prepared to teach children how to observe simple natural phenomena, for its second recommendation was that special science teachers be appointed to instruct the teachers of elementary schools in the methods of teaching. The conference was clearly of opinion that from the beginning this study should be pursued by the pupil chiefly, though not exclusively, by means of experiments and by practice in the use of simple instruments for making physical measurements. * * * At the same time the report points out that laboratory work must be conjoined with the study of a text-book and with attendance at lectures or demonstrations. * * *

It already appears that the nine conferences have * * * discussed fully the proper limits of the several subjects of instruction in secondary schools, the best methods of instruction, and the best methods of testing pupils' attainments. The conferences were equally faithful in discussing * * * the most desirable allotment of time for each subject and the requirements for entering college.

The foregoing subjects are fully examined by the committee of ten in its report, and before making recommendations this committee has exhibited the suggestions of the conferences in tabular form. The suggestions of the conference on physics, chemistry, and astronomy are as follows:

For the elementary grades. primary and grammar schools (covering eight school years; pupils' age from 6 to 14 years): Study of natural phenomena five portions (units of time) a week during the first eight years, by experiments, including physical measurements. This study is to be coordinated with work in natural history (two portions, of not less than thirty minutes each, per week) and with work in geography (including astronomy, meteorology, etc.).

For the high-school grades (four school years; pupil's age from 14 to 18 years): Astronomy is to be elective and the time allotted to it is to be five portions per week for twelve weeks during the first two years; the third year of the high-school course is to be given to chemistry and the fourth to physics; meteorology or physiography is to be studied during the first two years; and meteorology (elective) during half of the third year, with geology or physiography (elective) for half of the fourth year.

The foregoing represents the suggestions of the conferences on astronomy, etc. It is not a programme, but the material from which a programme can be made. It has been studied in all its bearings by the committee of ten, which has constructed from it four tentative programmes, as given below.

All four programmes conform to the general recommendation of the conferences—that is, they treat each subject in the same way for all pupils, with trifling exceptions; they give time enough to each subject to win from it the kind of mental training it is fitted to supply; they put the different subjects on an approximate equality so far as time allotment is concerned; they omit all short information courses, and they make sufficiently continuous the instructions in each of the main lines, namely, language, science, history, and mathematics. With slight modifications they would prepare the pupils for admission into any American college; * * * and they would meet the new college requirements which are suggested below.

CLASSICAL COURSE.

[Three foreign languages, one modern.]

	Portions.
First year:	
Latin	5
English	4
Algebra	4
History	4
Physical geography	3
	20
Second year:	
Latin	5
English	2
German (or French) begun	4
Geometry	3
Physics	3
History	3
	20
Third year:	
Latin	4
Greek	5
English	3
German (or French)	4
Mathematics (algebra 2, geometry 2)	4
	20

Fourth year:

Latin	4
Greek	5
English	2
German (or French)	3
Chemistry	3
Trigonometry and higher algebra or history	3
	20

LATIN—SCIENTIFIC COURSE.

[Two foreign languages, one modern.]

First year:

Latin	5
English	4
Algebra	4
History	4
Physical geography	3
	20

Second year:

Latin	5
English	2
German (or French) begun	4
Geometry	3
Physics	3
Botany or zoology	3
	20

Third year:

Latin	4
English	3
German (or French)	4
Mathematics (algebra 2, geometry 2)	4
Astronomy, one-half year; meteorology, one-half year	3
History	2
	20

Fourth year:

Latin	4
English	4
German (or French)	3
Chemistry	3
Trigonometry and higher algebra or history	3
Geology or physiography, one-half year; anatomy, physiology, and hygiene, one-half year	3
	20

MODERN-LANGUAGE COURSE.

[Two foreign languages, both modern.]

First year:

French (or German) begun	5
English	4
Algebra	4
History	4
Physical geography	3
	20

Second year:

French (or German)	4
English	2
German (or French) begun	5
Geometry	3
Physics	3
Botany or zoology	3
	20

Third year:

French (or German)	4
English	3
German (or French)	4
Mathematics (algebra, 2; geometry, 2)	4
Astronomy one-half year, meteorology one-half year	3
History	2
	20

Fourth year:

French (or German)	3
English	4
German (or French)	4
Chemistry	3
Trigonometry and higher algebra or history	3
Geology or physiography, one-half year; anatomy, physiology, and hygiene, one-half year	3
	20

ENGLISH COURSE.

[One foreign language, ancient or modern.]

First year:

Latin or German or French	5
English	4
Algebra	4
History	4
Physical geography	3
	20

Second year:

Latin or German or French	[1] 5
English	[1] 3
Geometry	3
Physics	3
History	3
Botany or zoology	3
	20

Third year:

Latin or German or French	4
English	5
Mathematics (algebra, 2; geometry, 2)	4
Astronomy, one-half year; meteorology, one-half year	3
History	4
	20

[1] Or 4.

Fourth year:

Latin or German or French	4
English	4
Chemistry	3
Trigonometry and higher algebra	3
History	3
Geology or physiography, one-half year; and anatomy, physiology, and hygiene, one-half year	3
	20

These admirable programmes have been reprinted in full in this chapter in order to exhibit in the clearest manner the nature of the choice which may be made by the high-school student. If he is intending to continue his Greek studies in college (and not otherwise), he should follow the classical programme. Two years of Greek in the high school will fit him for entrance to college; but if he is to go no further in this direction, the time spent upon it can, without doubt, be better bestowed.

The remaining three courses can be considered with reference to two classes of pupils—(*a*) those whose tuition is to end with the high-school course and (*b*) those who propose to follow a college curriculum.

It does not concern us here to discuss the pupils of the first class. The last three courses all devote the same time to astronomy. Those students who propose to enter college may know whether they do or do not intend to pursue the study of astronomy during their college course. If they do, it is of immense importance that they should lay the widest possible foundations for their scientific knowledge and avoid too narrow and special a view of the world. On every account, it is desirable that they should follow what is here called the Latin-scientific course.

The grounds for such a choice will be more obvious later on; it is here sufficient to say that it can be advocated for purely utilitarian reasons. Every working astronomer should be able to read the writings of those masters of the science who have written in Latin, and he must be familiar with both German and French. One of these modern languages he may acquire in the high school. It is indispensable to devote the requisite time to acquiring the other during his college course. In the last section of this chapter treating of the training of an astronomer in the college and the university it is shown that the best disposition of a young student's time is that which gives him the broadest possible foundation for his subsequent special studies. He should comprehend the methods of all the sciences, not merely the method of his own science. The methods of the different sciences are different though their spirit is the same. Hence if it is known that a pupil in the high school intends to follow astronomy as a profession he should be encouraged to study the other sciences in his high-school course rather than astronomy. There will be plenty of time for that; and it is to his best interest to broaden all his sympathies and to widen his scientific interests. On the other hand, if it is not known what his future course is to be (as it generally will not be so early in his career), he should by all means choose astronomy as one of the group of scientific studies. In the construction of these programmes the committee of ten has adopted as the unit of time a "period." Its length in minutes is not here defined. The committee remarks that its maximum of twenty "periods" per week is subject to two qualifications, namely, at least five of the twenty periods should be given to unprepared work, and laboratory subjects should have double periods whenever this prolongation is possible.

The committee notes the omission of certain subjects from these programmes—music, drawing, elocution, etc.—and remarks that it is left to school authorities to determine how these subjects should be introduced into the programmes "in addition to the subjects laid down by the conferences."

It is the fixed opinion of the writer, and it is confirmed, I think, by the experience of teachers all over the world, that a place should be made for drawing in these programmes, even if the time for it must be subtracted from the hours allotted to the other subjects. This judgment can be defended on many and very various grounds. In this place it may be sufficient to point out that the power to represent with the pencil what he sees (in the telescope, in the microscope, with the naked eye) is absolutely indispensible to the man of science. It is not possible to teach young persons to observe natural phenomena critically unless they are likewise taught to record their observations promptly and accurately. For this reason—not to speak of other reasons—it appears to be essential to introduce drawing as a fixed part of the instruction in every course which has to do with natural phenomena. If the exigencies of the programmes demand it the necessary time should be taken from the hours allotted to science. It is exactly true that science can not be properly taught, that observations can not be properly made, unless the student is trained to record his work graphically at the time, in order that he may study and compare it at leisure later on.

These considerations are discussed by the various conferences and they are insisted on by the committee of ten in what follows:

Drawing does not appear as a separate subject in the specimen programmes, but the careful reader of the conference reports will notice that drawing, both mechanical and free-hand, is to be used in the study of history, botany, zoology, astronomy, meteorology, physics, geography, and physiography, and that the kind of drawing recommended by the conferences is of the most useful kind, namely, that which is applied to recording, describing, and discussing observations. * * *

The committee of ten think much would be gained if, in addition to the usual programme hours, a portion of Saturday morning should be regularly used for laboratory work in the scientific subjects. * * * The committee venture to suggest further that, in addition to the regular school sessions in the morning, one afternoon in every week should be used for out-of-door instruction in geography, botany, zoology, and geology, * * * [meteorology, astronomy, by day or night, as necessary]. At the beginning the pupil will need a large amount of individual instruction in the manipulation of specimens, the use of instruments, and the prompt recording of observations.

The paragraphs of the report of the committee of ten that refer to the matter of the requirements for entrance to colleges relate to the topics treated in the present chapter in a very direct manner. They need not, however, be quoted here. It is sufficient to refer to pages 51 and 52 of their printed report. Again, every one who has had to do with education recognizes the great need of better-trained teachers (especially of science) in American secondary schools. The recommendations of the committee of ten in this regard also are most important (their report, p. 52), and they rightly point out that an enlargement of sympathies and a broadening of interests are quite as much needed as improvements in apparatus and appliances. These general subjects, which are treated by the committee in a broad and general manner, have specific relations to the special subject treated in this chapter. When once the general principles laid down by them are comprehended and admitted it is a mere matter of detail to apply the principles to a particular case, to the teaching of the sciences, or to the teaching of any special science, as astronomy.

REPORT OF THE CONFERENCE ON PHYSICS, CHEMISTRY, AND ASTRONOMY.

From the report of this conference a few paragraphs are selected in order to emphasize certain conclusions of the committee of ten. A few comments are interspersed in brackets. The conference recommended:

That the study of simple natural phenomena be introduced into the elementary schools, and that this study, so far as practicable, be pursued by means of experiments carried on by the pupil; also that in connection therewith, in the upper grades of these schools, practice be given in the use of simple instruments for making physical measurements.

That at least two hundred hours be devoted to the study of physics in the high school.

That at least two hundred hours be devoted to the study of chemistry in the high school.[1] (The study of chemistry to precede that of physics.)

That both physics and chemistry be required for admission to college [of all students?].

That astronomy be not so required.

That when the high-school course is four years, an elective in astronomy be offered. Time: Five recitations per week during a period of twelve weeks.

That there should be no difference in the treatment of physics, chemistry, and astronomy for those going to college or scientific school and those going to neither.

That the study of astronomy should be by observation as well as by class-room instruction.

That, in the opinion of this conference, it is better to study one subject as well as possible during the whole year than to study two or more superficially during the same time. [The form of this resolution appears to be scarcely happy. As it stands it expresses a judgment from which no teacher of science could differ. No one would be content with superficial teaching. It is probable that the conference intended to emphasize their desire for thoroughness. All teachers would agree that scientific instruction in high schools to be useful must be thorough. The conference probably further intended to convey a warning that our received ideas of thoroughness were none too high, and to insist on thoroughgoing work.]

That in the instruction in physics and chemistry it should not be the aim of the student to make a so-called rediscovery of the laws of these sciences. [In astronomy there could not be better instruction than to put the student in the position occupied by the great discoverers at the instant before their discovery was made and to make it inevitable that the student should himself take the last step. This can occasionally be done in some topics, and with clever pupils, and when it has been done a great step has been gained. As a method to be followed in all topics it is rightly condemned. It has relations, however, with the method of teaching science by reviewing its history, by connecting the successive steps in discovery with the lives and actions of special scientific men, and there is little doubt that the historic method of expounding science has wide applications. The resolution of the conference is one that all men of science can agree to. On the other hand, such an agreement must not be allowed to limit the scope of good teaching. This is undoubtedly the view of the conference itself, whose words in explanation of this resolution are: "The pupils may, to be sure, become imperfectly acquainted with the methods of work which have led to the discovery of laws and they will, no doubt, come to see more and more clearly the relations between the facts and the laws, but the conference is clearly of the opinion that it is wrong to speak of the work of the pupils as leading to the discovery of laws."]

One word may be added here on the outside reading of scientific books by high-school pupils. The student in the secondary schools who shows a taste for any particular study, as astronomy, should be encouraged to read books on the subject, even if the books are somewhat above his full comprehension. The biographies of great astronomers may be of intense interest to a clever lad. He certainly can not understand the details of their discoveries, nor comprehend the methods which they invented and employed. But their persistence, single-mindedness, and devotion, their moral qualities, will impress him deeply and may lead him to follow their path or another no less worthy. The creation of a generous enthusiasm in the growing boy is no small matter. The teacher himself will gain inspiration from the reading of such books as the biographies of scientific men, written by Arago for the French Academy of Sciences (an English translation exists), and the like, and this inspiration may be transferred to the pupils. A real enthusiasm is contagious. To give a young mind a model that can be sincerely admired is a great gift.

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[1] The writer of this chapter fully agrees with the minority report to the conference which would assign not more than one hundred and fifty hours to chemistry, since physics has only two hundred.

APPARATUS—INSTRUMENTS.

It is best to have a simple set of appliances for students in the secondary schools. A large part of the apparatus should be made by the pupils themselves, but their time should not be wasted in the fabrication of telescopes, either refractors or reflectors, as is recommended by some instructors. An object glass or a speculum is a very delicate contrivance, and it requires much time to construct even a passable one. The construction of a poor one teaches no lesson, except, perhaps, that it had better not have been attempted. Nearly every school can afford to own a powerful field glass, or, better, a spyglass, magnifying 8 diameters or more. The students themselves can construct a simple equatorial mounting (stand) for such a spyglass, with large wooden circles divided to 5 degrees in declination and, say, to 20 minutes in right ascension. A simple pointer, moving with the telescope, will enable the pupil to point the instrument with some accuracy, which will be a great convenience. If a spyglass can not be had, a mounting of the sort should be constructed, nevertheless, and a straight rod, some 2 or 3 feet long, fastened to it as a pointer (as if the rod were a telescope). All kinds of problems can be solved or illustrated by a device of this sort.

A straightedge, some 3 feet long, should also be provided. By holding it in the hand, so that the edge passes through three stars (or through two fixed stars and a planet) the relative position of the stars is fixed with considerable accuracy. The daily motions of planets can be studied in this way. Two cheap watches may easily be obtained as a part of the permanent apparatus of the school. One of them should be regulated to mean solar the other to sidereal time.

A terrestrial globe and a celestial globe can be used in very many ways. "The use of the globes" comprises most of the problems of spherical astronomy. The larger they are the better, since angles can be measured on them with more accuracy.

It is a great convenience to have a globe (the larger the better) made of slate and blank, so that circles and points can be drawn on the surface with chalk. All kinds of uses will be found for such a globe, and whenever possible it should be taken out of doors and the lines on the globe compared with the circles in the sky.

If a celestial globe is not available a set of star maps can be had for a small sum. (Proctor's Half-Hours with the Stars, G. P. Putnam's Sons, New York, is as convenient as any of the cheaper atlases. McClure's Edition of Klein's Star Atlas, S. D. U. K. Co., New York, is fuller and in some respects more satisfactory.)

A small compass will be found useful in fixing the (approximate) position of the meridian or, better, a meridian line can be established near the school building once for all. To lay out such a line will be a good exercise for the students.

A sundial can be constructed empirically or by theory; and a straight stick for a gnomon will serve to elucidate many problems. (Equal altitudes of the sun, morning and afternoon; the sun's maximum altitude; the date of the solstices, etc.)

The school should gradually acquire a little library of astronomical books. Besides the atlases already named, it should own Serviss' Astronomy with an Opera Glass, Webb's Celestial Objects, and popular elementary books, by Sir Robert Ball, Flammarion, Proctor, and others, and the text-books of Howe, Newcomb, Holden, Young, and others. It is not necessary to give a list of these. The teacher can make a selection after examination.

It would be easy to suggest more elaborate appliances and to give the titles of books for an adequate library of reference and for reading; but it is desired to emphasize the fact that while expensive apparatus can be very well utilized, it is not essential.

III. COURSES OF INSTRUCTION IN ASTRONOMY OFFERED BY SOME AMERICAN UNIVERSITIES AND COLLEGES.

From the annual catalogues of various universities I have taken the following paragraphs, which exhibit, briefly, the instruction offered to students in astronomy. An examination of these programmes will exhibit the present state of instruction in astronomy in American colleges in a very satisfactory manner.

HARVARD UNIVERSITY.

Undergraduate courses in astronomy.

Descriptive astronomy three times a week for first half year.

Practical astronomy (use of instruments and applications to navigation and surveying); lectures and laboratory work three times a week for second half year. (This course is intended primarily for students of civil engineering. It requires a working knowledge of trigonometry and of solid geometry.)

Practical astronomy (determination of time, latitude, and longitude); use of the sextant and astronomical transit; lectures, instrumental work and computations, three times per week for one year. (This course requires a working knowledge of trigonometry and of solid geometry. It may be taken as a whole instead of the two courses just given.)

HARVARD COLLEGE OBSERVATORY.

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Instruction in astronomy is not given at the observatory, either by lectures or recitations. Facilities are freely offered to astronomers for making use of the library, buildings, grounds, and instruments of the observatory so far as this can be done without interfering with regular work. Similar opportunities are sometimes offered to special students in astronomy, but the constant employment of the principal instruments greatly limits the use that can be made of them for this purpose. Such students may apply for admission to the director, with whom the fees for the privileges offered may be agreed upon. In some cases a part or the whole of the fees may be remitted in consideration of services rendered in computation.

YALE UNIVERSITY.

Graduate courses.

Geodesy and practical astronomy, one half year. (Methods of observation, based on measurements, triangulation, field work, theory of least squares, adjustment of observations, computation of geodetic latitude, longitude, and azimuth. The study of practical astronomy embraces the use of the sextant and engineer's transit * * * for determining time, latitude, azimuth, and needle variation.)

Descriptive astronomy. (Three hours per week for a half year.) This is an undergraduate course. Text-book: Young's Elements of Astronomy.

Navigation and nautical astronomy. (Two hours per week for one year.) This is also an undergraduate course which treats mostly of nautical astronomy, with practice in the use of the sextant.

Practical astronomy (two hours per week for one year). This also is an undergraduate course. (It consists of observatory work with astronomical transit and chronograph for determination of sidereal and standard time, and with sextant and theodolite for determination of latitude and azimuth, numerical computations for reduction of observations, derivation of formulæ, and recitations from Loomis's Practical Astronomy.)

YALE UNIVERSITY OBSERVATORY.

In the official announcements regarding the observatory of Yale University no mention whatever is made of its relation to students. It is there described as an institution devoted entirely to research. It is known, however, that special students of promise have been received somewhat on the footing of assistants, and the higher degrees may be taken by students in astronomy who may make practical astronomy a part of their regular work.

COLUMBIA UNIVERSITY.

General astronomy (historical and descriptive). Elective for juniors and seniors in the college. Two hours per week for one year. Reference books: Young's General Astronomy, Clerke's History of Astronomy and System of the Stars, Grant's History of Physical Astronomy.

Spherical and practical astronomy (use of the sextant and transit). Reference book: Campbell's Practical Astronomy. Two hours' lecture and two hours' observatory work throughout the year. Elective for seniors.

Advanced spherical and practical astronomy. Reference books: Chauvenet's Astronomy, Doolittle's Astronomy. Two hours' lectures and four hours' observatory work for two years. This is essentially a course for graduates.

Theoretical astronomy (theory of cometic orbits). Reference books: Klinkerfues's Theoretische Astronomie, and Oppolzer's Bahnbestimmung, one hour per week, supplemented by computations for two years. A graduate course.

Theory and methods of reduction of photographic star plates, one hour per week, supplemented by computations for two years. A graduate course. The university possesses an observatory fully equipped for teaching. Instruction in geodesy is also offered.

UNIVERSITY OF MICHIGAN.

Undergraduate courses.

General astronomy, three hours per week for one term.

Spherical astronomy, three hours per week for one term.

Practical exercises in computing, three hours per week for one term.

Theory and computation of parabolic orbits, five hours per week for one term.

Elementary practical course, one hour per week for one term.

Practical astronomy (use of the sextant and transit), three hours per week for one term.

Extended practical course (as specially arranged).

Theory and computation of elliptic orbits, special perturbations, five hours per week for one term.

Spherical astronomy continued, three hours per week for one term.

Lectures on the recent progress of astronomy, one hour per week for one term.

Mathematical theories of planetary motions, three hours per week for one term.

In the engineering department there are two other courses, viz, practical exercises in computing, three hours a week for one term, and practical astronomy (use of the portable transit), three hours a week for one term.

The university possesses two observatories, viz, the astronomical observatory proper and a students' observatory, for instruction only. It is a noteworthy fact that no other American university has sent forth so many working astronomers as Ann Arbor.

PRINCETON UNIVERSITY.

Undergraduate courses.

Elementary astronomy. Lectures, text-book. Junior elective, first term, two hours per week. Text-book, Young's General Astronomy.

General astronomy, extended course. Astronomical instruments and methods, astronomical constants, undisturbed planetary motion, spectroscopic astronomy.

Lectures and recitations. Senior elective, first term, two hours per week. Text-book, Young's General Astronomy.

Practical astronomy. Determination of time, latitude, azimuth, and the positions of planets and comets. Spectroscopic observation of the sun. Recitations and observatory work. Senior elective, one year, two hours per week. Text-books, Campbell's Practical Astronomy, Chauvenet's Practical Astronomy.

Theoretical astronomy. Theory and calculation of orbits. Graduate course, one year, one hour per week. Text-books, Watson's Theoretical Astronomy. Oppolzer's Bahnbestimmung, Klinkerfues's Theoretische Astronomie.

The foregoing courses are open to all students, and some of them are required in the school of science. The extended courses of theoretical and practical astronomy (with additional work) are designed for graduate students also. The school of science offers instruction in higher geodesy also. The university possesses two observatories, namely, the Halstead observatory, which is appropriated to scientific work, chiefly in the department of astronomical physics, and an observatory for instruction.

This [latter] establishment is devoted entirely to the use of students, and is fully equipped for its purpose. It possesses an equatorial (by Clark) of 9½ inches aperture, with a full complement of spectroscopic and other accessories. It has also a 9-inch reflector, a meridian circle, * * * two transit instruments, * * * a prime-vertical transit, * * * etc. There are also a number of sextants, and all the other subsidiary apparatus required for carrying out the work involved in the courses on practical astronomy.

UNIVERSITY OF VIRGINIA.

Undergraduate course.

A course of general astronomy is given. Text-books: Howe's Elements of Descriptive Astronomy, Barlow's and Bryan's Elementary Mathematical Astronomy, Young's General Astronomy.

Graduate courses.

During the year 1897-98 the following courses are offered: (1) The history of astronomy; (2) motions of the solar system; (3) least squares; (4) the lunar theory.

Systematic training is also given in numerical computation and in the use of astronomical instruments, and students are encouraged to engage in such original work as their time and attainments may permit.

Students have the use of certain instruments in the observatory also.

AMHERST COLLEGE.

Undergraduate courses.

There are two courses, both elective, as follows:

First term, four hours per week; Young's General Astronomy, with lectures on the history of astronomy.

Second term, four hours a week; practical astronomy (text-books of Loomis and Souchon); theoretical astronomy (Watson's Theoretical Astronomy); observatory work.

BROWN UNIVERSITY.

Undergraduate courses.

General astronomy; one year, three hours per week; elective for juniors and seniors.

Practical astronomy; two-thirds of a year, three hours per week. Elective. The application of astronomy in navigation and geodesy; theory and use of instruments; astrophysics; solar and stellar spectroscopy; astronomical photography; infra-red radiations; history of astronomy. One year, three hours per week; elective for senior and graduate students. The well-equipped observatory is available to students.

WILLIAMS COLLEGE.

Undergraduate courses.

Elementary astronomy; the art of computation; descriptive astronomy; the history of astronomy; practical exercises with instruments. Junior elective course, three hours per week for one year.

Exercises in practical astronomy. "The object of the course is to give additional practical knowledge of the subject and facility in handling instruments and using formulæ;" computation of comet orbits. Senior elective course; three hours per week for one year.

Graduate course.

A course of instruction in practical astronomy is offered to graduates or persons qualified to pursue it. It will include the following subjects: Theory and use of instruments; the art of computation; the method of least squares; reduction, criticism, and discussion of observations; computation of the orbits of comets and planets; special and general perturbations; higher geodesy. The (two) observatories of the college are fully available for the work of instruction.

UNIVERSITY OF WISCONSIN.

Undergraduate courses.

General astronomy, half a year, three hours a week. Text book: Young's General Astronomy, with collateral reading.

General astronomy. A continuation of the foregoing course, with special reference to modern developments in astronomical physics, together with observatory work five times a week during the spring for two hours a day (night). Full study throughout the year.

Theoretical astronomy. Integration of the equations of motion and the computation of ephemerides; determination of the elements of an orbit; special perturbations.

Graduate courses.

Graduate students and others will be received into the Washburn Observatory as assistants, and will take part in the regular observations of the astronomers, at the same time continuing their theoretical studies. Facilities for original work are given, and such work from students, if worthy, is printed in the regular publications of the observatory.

Besides the Washburn Observatory, the university possesses a special student's observatory designed by Professor Watson.

JOHNS HOPKINS UNIVERSITY.

Undergraduate courses.

A course in general astronomy is offered as an elective for third-year students. The course embraces an historical sketch of the development of the science and an outline of the present state of our knowledge of the constitution and motion of the celestial bodies. The use of the principal instruments is explained and some practice is had with the equatorial.

Graduate courses.

For those students who wish to take astronomy as a subordinate subject, a general outline course is given each year. This course is intended to familiarize the student with the most important problems of spherical and practical astronomy, with the principles and general methods of gravitational astronomy and with the history and literature of the subject. There is also given every year a more advanced course. * * * Among the subjects treated of in this course are the theories of precession and nutation, the computation and the correction of orbits, and the methods of computing special perturbations. The advanced courses vary from year to year. Such courses embrace the method of least squares, the theory of measuring instruments, celestial mechanics generally, * * * and the various methods of treating and integrating the equations of planetary motion.

The foregoing statement gives a general idea of the design of the courses given by the university. For details reference should be made to the circulars of the university.

UNIVERSITY OF PENNSYLVANIA.

Undergraduate courses.

General astronomy; text-book, Young's General Astronomy, three hours a week for one term. Prescribed course for juniors and seniors in certain courses.

Practical astronomy; text-book, Doolittle's Practical Astronomy, three hours a week for one term. Prescribed for juniors and seniors in certain courses. This course includes practical work with the sextant, transit, etc.

Practical astronomy (*continued*), with the theory of eclipses, precession, etc., least squares. Prescribed for certain seniors. Three hours per week [for one year].

Theoretical astronomy; text-books, Watson and Oppolzer. Prescribed for certain seniors. Two hours per week [for one year]. "Graduate students are instructed in the details of observatory practice, and participate in the regular work" of the astronomers of the Flower Observatory.

UNIVERSITY OF CHICAGO.

[The elaborate programme of the University of Chicago is given nearly in full, as it is very instructive in several respects.]

Courses of instruction for undergraduates and for graduates.

[M=Minor course—a single course for six weeks. DM=Double minor course—a double course (two hours daily) for six weeks. Mj=Major course—a single course for twelve weeks. DMj=Double major course—a double course for twelve weeks.]

AT THE UNIVERSITY.

I. Elementary (senior college) courses (1-20).
   1. Popular lectures.
   2. History of astronomy: Introduction. The apparent motions of the heavenly bodies as explained by the ancient astronomers. The system of Copernicus. Newton's general law of gravitation, modern astronomy. M. First term, summer quarter; 9.30 a. m. Mj. Winter quarter; 9.30 a. m.
      Prerequisite: Algebra and the elements of physics.
   3. General astronomy: An elementary course dealing with fundamental facts, principles, and methods. Mj. Autumn quarter; 11 a. m.
      Prerequisite: Algebra, trigonometry, and the elements of physics.
   4. Introduction to physical astronomy: The action of central forces; Laplace's demonstration of the law of gravitation; equations of motion; elements of the orbits; planetary integrals; invariable plane; perturbations; applications to the motion of the moon, planets, and satellites; rotation of the planets, precession, and nutation. Mj. Winter quarter; 11 a. m.
      Prerequisite: Differential calculus.
   6, 7. Spherical and practical astronomy: Part I. Introduction: The principal theorems of spherical trigonometry, interpolation:
      I. The different systems of polar coordinates used in astronomy. The measurement of time.
      II. Changes of the fundamental planes of reference; (1) precession; (2) nutation.
      III. Theory of the corrections of observations due to (1) parallax; (2) refraction; (3) aberration.
      IV. Star catalogues and their use.
         To be followed by 7.
         Mj. Winter quarter; 9.30 a. m.

7. Part II. With practical work in the students' observatory. Theory of the astronomical instruments. Determination of time and latitude, of absolute right ascensions and declinations of stars. Determination of longitude. To be preceded by 3. Mj. Spring quarter; 9.30 a. m.
   Prerequisite: General astronomy and differential and integral calculus.
8. Determination of latitude and longitude, with practical work in the observatory. Transformation of the different systems of coordinates; sidereal and mean solar time. Theory of the universal instrument; determination of its errors from observations. Determination of time and latitude by observation; theory of the determination of longitude. Mj.
   Prerequisite: General astronomy and differential and integral calculus.
9. Observatory work. Practice with the equatorial and with the universal instrument in the students' observatory. Mj. Spring quarter.
11. Determination of the parabolic orbit of a comet. Integration of the differential equations for the problem of two bodies. Relation between several places in the orbit; determination of the position of the orbit in space; corrections to be applied to the observed places and deduction of the elements of the orbit. Computation of an ephemeris. The theory will be applied to a special case to be selected from the list of comets recently discovered. Mj. Spring quarter; 11 a. m.
   Prerequisite: Differential and integral calculus and general astronomy.
12. Determination of an elliptic orbit from three complete observations. The general theory is very similar to that of (5) except that is the case of an elliptic orbit, six elements are to be determined instead of the five of a parabolic orbit. Application of the theory to the orbit of one of the small planets. Mj. Summer quarter; 8.30 a. m.
   Prerequisite: Differential and integral calculus and general astronomy.
13. Determination of the orbit of a double star: Historical sketch of the different methods used. Kowalsky's method, modification proposed by Glasenapp. Graphical method of Klinkerfues. M. Second term, summer quarter; 9.30 a. m.
   Prerequisite: Analytical geometry.
14. Theory of probability and method of least squares. Mj.
   Prerequisite: Differential and integral calculus.

II. Advanced (graduate) courses (21–50).

21, 22. Analytical mechanics. 21. Statics (Part 1): Composition and equilibrium of forces applied at a point. The center of gravity of lines, surfaces, and volumes. Attraction of bodies upon a point. Kinematics: Acceleration, the rectilinear and the curvilinear motion of a material point and the forces that produce them. To be followed by 22. Mj. Autumn quarter; 8.30 a. m.

22. Statics (Part 2): Composition and equilibrium of forces applied to an invariable system; principle of virtual velocities. Dynamics: Principle of d'Alembert, moments of inertia; rotation of a body around an axis; general motion of a system of bodies. Rotation of a body around a point. To be preceded by 21. Mj. Winter quarter; 8.30 a. m.
   Prerequisite: Differential and integral calculus and differetial equations.

23. Spherical harmonics.
   I. Spherical harmonics with one variable—general theory; development of functions in spherical harmonics; spherical harmonics of the second kind and associated functions.
   II. Spherical harmonics with several variables—general theory; development and properties of the functions C and S. Mj.

24. The problem of three bodies. Introduction: (*a*) The integrals of the differential equations of a system of n bodies; (*b*) the integrals for $n=2$:
   I. Lagrange's investigations. Œuvres complètes, VI, pp. 229–334.
   II. Jacobi's investigations. Gesammelte Werke, IV, pp. 295–314.
   III. The investigations of modern mathematicians and astronomers. Mj.
   Prerequisite: Advanced integral calculus.

25. Dynamics of a system of bodies based upon the lectures of Jacobi. Differential equations of the motion of a system of material points; dynamical principles of; conservation of the motion of the center of gravity; conservation of vis viva; conservation of areas; principle of least action; Lagrange's multipliers; Hamilton's form of the differential equations; theorems of Jacobi. Applications of the method of Hamilton and Jacobi to mechanical problems. The theory of the variation of constants; introduction to the perturbing function. Mj.
   Prerequisite: Differential and integral calculus, and analytical mechanics.

31. The motion of a heavenly body in a resisting medium. Mj. Autumn quarter; 9.30 a. m.
Prerequisite: Differential and integral calculus.
32. Special perturbations. Numerical differentiation and integration; development of the differential equations for perturbations in rectangular and polar coordinates; variation of constants. Mj.
Prerequisite: Differential and integral calculus, and elements of the theory of orbits.
33. Theory of absolute perturbations based on the methods of Laplace. The differential equations for undisturbed motion, elements of the orbit; differential equations for disturbed motion; integration by successive approximation, determination of the perturbations in the radius vector, longitude and latitude. Development of these expressions in series adapted to the formation of planetary tables. Mj.
34. Theory of absolute perturbations: Lagrange's theory of variation of elements. Approximate integration of the differential equations of motion. Secular values of the elements; the periodical terms of the elements. The stability of the planetary system. Long-period inequalities arising from the near approach to commensurability in the mean motions. Short history of the theories of perturbations. Mj. Summer quarter; 7.30 a. m.
Prerequisite: Differential and integral calculus, and theory of orbits.
35. Gauss's method of determining secular variations, with numerical application to the action of the earth on Mercury. Derivation of the formulæ for the variation of the elements; substitution of a certain form of elliptical ring which will give the same mean action as the moving planet; determination of the mutual action of two such rings by means of elliptic integrals of the first and second kinds; development of the formulas for the secular variations of the elements as given by Hill; application of the method of Gauss to the action of Neptune on Uranus; comparison of results with those found by Leverrier from the series expanded in powers of the eccentricities and mutual inclination of the planes of the orbits. Mj. Spring quarter; 9.30 a. m.
Prerequisite: Elements of the theory of perturbations and of elliptic integrals.
36. Selected chapters of Poincaré's: Les méthodes nouvelles de la mécanique céleste. Mj.
Prerequisite: Course 17.
41. Theory of the attractions and figures of the heavenly bodies.
I. Determination of the attractions of homogeneous sphere, spherical shell, heterogeneous sphere made up of layers of uniform density, homogenous ellipsoid, spheroid of revolution differing but little from a sphere. Development of the attraction of an oblate planet in a series of spherical harmonics, following the method of Laplace.
II. Figures of equilibrium of sphere, spheroid, Jacobi's ellipsoid of three unequal axes, figures of Poincaré and Darwin. Application of the theory of the equilibrium of a fluid mass endowed with a rotary motion to the figures of the planets. Mj. Spring quarter; 8.30 a. m.
42. Theory of a rotating body. (*a*) Euler's equations for undisturbed motion; equations of Poisson and Serret for disturbed motion, with a development of the perturbing function; precession and nutation. (*b*) Rotatory motion of a body of variable form. Mj. Spring quarter; 8.30 a. m.
Prerequisite: Differential and integral calculus, and analytical mechanics.
50. Astronomical seminar. ½Mj. Summer quarter; Sat., 8.30–10.30 a. m.

AT THE YERKES OBSERVATORY.

In the work at the Yerkes Observatory the advanced student is made familiar with modern methods of research in various branches of astronomy and astrophysics. In general, the work in progress during the year 1897–98 will probably include: Researches in solar physics with the spectroscope, spectroheliograph, photoheliograph and bolometer; micrometric observations of double stars, planets, satellites, nebulæ, and comets; studies of stellar spectra; researches on the infrared spectra of the elements; special astrophysical investigations. On account of the unfinished condition of the observatory and the nature of the work, it is possible that the subjoined outline of courses will require some modification.

GRADUATE COURSES.

51, 52, 53. Solar physics. Visual and photographic study of the solar photosphere, spots, and faculæ. Use of the photoheliograph. DMj. Autumn quarter.

Spectroscopic observations of sun-spots, including systematic study of widened lines and detailed investigations of particular lines. DMj. Winter quarter.

Visual and photographic observations of the chromosphere, prominences and faculæ, with the solar spectroscope and spectroheliograph. Systematic records of areas; researches on special problems; measurements and reductions of photographs. DMj. Spring quarter.

Prerequisite: Practical astronomy, advanced physics and laboratory practice, spectrum analysis.

54. Bolometric investigations. Mj. Summer quarter.

55. Stellar spectroscopy. Including measurement of motion in the line of sight and detailed studies of peculiar spectra. DMj. Autumn quarter. Prerequisite: Solar physics.

56. Radiometric work. Mj. Summer quarter.

57. Instrument design and construction. Mj. Summer quarter.

58. Researches in solar physics. Mj. Summer quarter.

59, 60, 61. Astrophysical research. Character and prerequisites will be announced later. DMj. Autumn quarter. DMj. Winter quarter. DMj. Spring quarter.

62. Special research. Mj. Summer quarter.

WESTERN UNIVERSITY OF PENNSYLVANIA.

Post-graduate course of instruction in astronomy and astro-physics.

Instruction is given by means of lectures, recitations, and examinations, and by the practical use of instruments in observation and measurement. A knowledge of mathematics equivalent to that given in the undergraduate department of this university is requisite for admission to the course, which will extend over a term of two years.

While instruction in astro-physics has been regarded as of chief importance in arranging the course, no student will be allowed to graduate without a good knowledge of the facts and principles of general astronomy and the methods of practical astronomy. The student who completes the entire course and passes successfully the prescribed examinations, and in addition presents a thesis embodying the results of his own original investigations, will receive the degree of Ph. D. in course. An outline of the subjects treated, and a list of books which will be used either as text-books or as works of reference is given below:

1. The facts and principles of general astronomy; problems, projection of eclipses, etc. Young's General Astronomy.

2. The chief operations of practical astronomy, and use of instruments.

The sextant, and artificial horizon. Latitude by circum-meridian altitudes of the sun. Latitude by Polaris. Time by single altitudes and by equal altitudes of the sun.

The transit instrument. Adjustment and determination of constants. Observation for time by eye and ear and by chronograph. Determination of right ascensions. Reduction of time observations by the method of least squares. Method of determining longitudes by the electric telegraph.

The equatorial. Adjustment. Use of filar and ring micrometers. Power of eyepieces. Polarizing eyepiece for solar observations. Longitude by occultations.

Books of reference: Chauvenet's Spherical and Practical Astronomy, Doolittle's Practical Astronomy, Campbell's Practical Astronomy.

3. The theory and use of the spectroscope. Construction and adjustment of various forms of the instrument. Gratings, flat and concave. Measurement of wave lengths. Construction of interpolating curves for prismatic spectroscopes.

Observation of solar prominences. Observation of the spectra of stars and nebulæ. Determination of the color curve of an objective. Study of the instruments used in the principal observatories, and of special instruments in course of construction at Brashear's optical works.

Scheiner's Spectralanalyse der Gestirne; Von Konkoly's Handbuch für Spectroscopiker; Parkinson's Geometrical Optics; Preston's Theory of Light; Lord Rayleigh's Papers on the Spectroscope.

4. Astro-physics and celestial spectroscopy. Lockyer's Chemistry of the Sun; Miss Clerke's History of Astronomy in the Nineteenth Century; Miss Clerke's System of the Stars; Schellen's Spectrum Analysis; Scheiner's Spectralanalyse der Gestirne; Huggins's Papers on Stellar and Nebular Spectra; Langley's Papers on Solar Physics and on Atmospheric Absorption.

5. Astronomical photography. (Instruction will begin with ordinary photographic processes, in case the student is not already acquainted with them.)

Photographic objectives. Study of methods in use at the principal observatories. Methods of the Astro-Photographic Congress. Practice with the telescope.

Instruction in general astronomy is given to the members of the senior class by the professor of mathematics, the class rooms being in Science Hall. Some opportunity for practical observation is given them at the observatory.

The director of the Allegheny Observatory also gives 10 to 12 lectures to undergraduates each year on elementary practical astronomy. These lectures are addressed to juniors in college and to engineering students.

UNIVERSITY OF CALIFORNIA.

Courses in astronomy, at Berkeley.

1. Modern astronomy. (*a*) An introductory course during the first term. General facts and principles underlying the science of astronomy in all its branches. (*b*) Second term. Progress in astronomy through modern methods, especially spectroscopic and photographic. Two hours, throughout the year.

Open to all students. For observatory work in connection with this course, students will ordinarily elect Course 2; but may, instead, take Course 4A, or Course 4B, subject to the prerequisites announced.

2. Supplement to Course 1. Practice in observing. One or two evenings a week in the observatory. Three hours, or six hours, throughout the year (as the student may elect).

Open to students who are taking or have taken Course 1 or Course 3.

3. General astronomy. Young's General Astronomy. Three hours, first half.

Prerequisite: At least Junior standing; a knowledge of general physics. Prescribed, Junior year, in the course in astronomy and geodesy, college of civil engineering. For observatory work in connection with this course, students other than those in the course in astronomy and geodesy may elect Course 2, Course 4A, or Course 4B, subject to the prerequisites announced.

4A. Practical astronomy. Lectures and observatory work. Campbell's Astronomy. Clarke's Geodesy. Navigation and nautical astronomy. Practical work in the observatory. Six hours, observatory, first half. Three hours lecture and six hours observatory, second half.

Prerequisite: Either Course 1 or Course 3 in astronomy. The course should also be preceded by the course in differential and integral calculus, etc. Prescribed, Junior year. in the course in astronomy and geodesy, college of civil engineering.

4B. Practical astronomy. The subject-matter of Course 4A more briefly presented, and adapted to the needs of civil engineers. Second half. Usually given as one lecture and two observatory periods per week.

Prerequisite: As for 4A. Prescribed, senior year, in the course in railroad engineering.

5. History of Astronomy. Three hours, first half.

Prerequisite: Course 1 or Course 3. Prescribed, Senior year, in the course in astronomy and geodesy, college of civil engineering.

6. Theoretical astronomy. Four hours, throughout the year.

Prerequisite: Courses 3 and 4, etc. Prescribed, Senior year, in the course in astronomy and geodesy, college of civil engineering.

7. Method of least squares. The fundamental principles and processes of the method of least squares, and their application to the problems involved in the reduction of astronomical and physical observations. Two hours, first half.

Prerequisite: Working knowledge of the differential and integral calculus. Prescribed, Senior year, in the course in astronomy and geodesy. Elective in the college of mechanics, and in the course in railroad engineering, college of civil engineering.

[1] 8. Mechanical quadratures. Development of the formulæ of numerical differentiation and integration, and their application in the construction of tables. Three hours, second half.

Prescribed, Junior or Senior year, in the course in astronomy and geodesy, college of civil engineering.

[1] 9. Interpolation and the use of tables. The more useful formulæ of interpola-

[1] Courses 8 and 9 are offered in alternate years.

tion, and their application in the use of astronomical and other tables. Practice in extensive numerical computations by means of tables, with special aim at rapidity and exactness. Three hours, second half.

Prescribed, Senior or Junior year, in the course in astronomy and geodesy, college of civil engineering.

10. Summer school. A continuation of Course 3. Four weeks during the summer vacation. In 1896, the students determined the latitude of the students' observatory, by the method of Talcott.

11. Advanced practical astronomy. Chauvenet's Spherical and Practical Astronomy. One hour, throughout the year.

Prerequisite: Course 4. Prescribed, Senior year, in the course in astronomy and geodesy.

12. Graduate course in theoretical astronomy. Two hours, throughout the year.

Prerequisite: Course 6.

REGULATIONS REGARDING STUDENTS AT THE LICK OBSERVATORY.

The regular course of undergraduate work in astronomy in the university is given at Berkeley. Students who are graduates of the University of California, or of a university or college of like standing, are received at the Lick Observatory to pursue a higher course of instruction in astronomy, provided that, after examination, they show themselves competent. Such students may become candidates for the higher degrees of the university, or they may be received as special students merely. Quarters at Mount Hamilton may be assigned to them during that portion of the year occupied in their work with the instruments, and in return for such quarters they will be required to execute such computations as are assigned to them.

Application for admission to graduate courses at the Lick Observatory may be made at any time to the recorder of the faculties, at Berkeley; and students will be admitted on the recommendation of the director, approved by the graduate council of the university.

Students at the Lick Observatory may either be (*a*) candidates for one of the higher degrees of the university, or (*b*) special students. The higher degrees offered are Master of Arts, Master of Science, and Doctor of Philosophy. All candidates for a master's degree must reside at Mount Hamilton at least four months, and all candidates for a doctor's degree at least eight months. It is expected that students will choose their time of residence at the observatory in the period from June to November.

Special students are received (usually during the favorable observing weather, June to November), and every facility, consistent with the scientific work of the establishment, will be given to them. They will be required to follow out some line of work to the satisfaction of the director, and they will usually be assigned as assistants to some one of the astronomers.

IV. PRINCIPLES WHICH SHOULD GUIDE IN FORMING COURSES OF UNDERGRADUATE AND GRADUATE INSTRUCTION IN ASTRONOMY IN UNIVERSITIES—RELATION OF A UNIVERSITY OBSERVATORY TO THE TEACHING OF GRADUATE STUDENTS.

In the year 1895 I made a report to the regents of the University of California on the subjects named under the title given above. I venture to reprint a part of it here, as it represents my matured views. It is necessary to recollect that the University of California has its seat in the town of Berkeley; that the Lick Observatory is situated on Mount Hamilton, some 90 miles distant; that this observatory, with its staff of astronomers, is mainly devoted to the advancement of science; that the university at Berkeley possesses an excellently equipped students' observatory, and that the services of several professors and instructors at Berkeley are available for teaching practical and theoretical astronomy.

UNDERGRADUATE INSTRUCTION AT BERKELEY.

There are four classes of undergraduates whose wants must be considered.

First. Students who wish to study elementary and descriptive astronomy as an information study to make themselves familiar with the principal methods and discoveries. The preparation required is algebra, geometry, and elementary physics. A short course of three hours per week for one term is ample for this purpose, as I know from personal experience. For the convenience of the many students who will wish to take this course, it should be given in the first term and, if necessary, repeated in the second term of each year. I regard this course as indispensably necessary. It must be remembered that the larger part of the students at Berkeley are college, not university students. The course can be prescribed by those faculties which desire so to do, but it should be open by election to students of all the colleges. It will be very largely attended and will be very useful.

Second. Students of the scientific colleges (chiefly of the college of civil engineering) who do not intend to pursue the study beyond their senior year, but who wish to be practically familiar with astronomical instruments (particularly the sextant, theodolite, and transit), and their use in determining local time, azimuth, latitude and longitude, and with the discussion of observations by the method of least squares. From any suitable programme of undergraduate instruction the faculty of the college of civil engineering will have no difficulty in selecting the special courses which provide for these wants. I do not myself see that courses in theoretical astronomy (determination of orbits, etc.) or in the history of astronomy should be prescribed for engineering students, though such students should be free to elect them. I would suggest that all students of this class should attend the summer school at Berkeley and assist the director of it when necessary.

Third. Students who desire an extended undergraduate course in astronomy, but who do not propose to carry on their studies after graduation. The courses provided for students of classes first and second above, together with theoretical astronomy, optics, spectroscopy, and such higher mathematics and physics as they have time for will probably satisfy this class of students. A very large proportion of their work should be elective.

Fourth. Students who wish to prepare themselves as undergraduates for graduate work at Mount Hamilton [or elsewhere]. The work of this class of students should be prescribed in part, with a large measure of group and free electives. A part of the prescription should be English, French, and German, if for no higher reason than a practical one. It is absolutely indispensable to a student of higher mathematics, physics, or astronomy that he should have at least an accurate reading knowledge of French and German. If he ever obtains results of importance he will wish to publish them, and to this end he should have practice in English composition under competent instructors. The main part of his professional study will be in the three branches of mathematics, physics, and astronomy. The very best undergraduate preparation for graduate work in astronomy is not so much astronomy itself as a sound and sufficient training in the higher mathematics and thorough and long-continued work in the physical laboratory. Astronomy is but a branch of physics. Its observations are similar to though often less refined than the physical measurements, etc., of the laboratory. They must be discussed by the mathematical theory of probabilities in both cases. The true training for an astronomer in his undergraduate years is thus a training in the methods of physical manipulation (whether in heat, light, electrics, magnetics makes little difference, as the underlying principles are the same) and a thorough training in the mathematical processes by which the most probable results are obtained from a mass of observations. A theoretical discussion of the orbit of a molecule is an admirable preparation for the subsequent determination of the orbit of a planet. Theoretical and practical optics is especially well fitted as a training for students of this class. Some of the practical work in optics might well be done with the instruments at Mount Hamilton, according to a plan laid down by the professor of physics [at Berkeley] and to his satisfaction. The manipulations that are learned in the physical laboratory ought to be the best preparation for the observations of the practical astronomer.

The above principles I believe to be true in a general sense and that they should govern in every programme of studies.

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The value to the student of a training in any science is measured not by the number of results placed at his immediate disposition, but by the degree in which he has mastered the spirit of the methods of that particular science; not by the inventory of new things which he sees just about him, but by the acquired power to discover for himself more distant and less obvious ones. In so far as he has acquired this power, in so far is he "educated" in the particular science. His vision is more intense, though as yet only directed to one side. Each science—mathematics, physics, astronomy, geology, biology, etc.—has its own particular methods. For the symmetrical development of a man of science it is very necessary that he should be able to see on more than one side. For this reason it is important that the comparative leisure of the undergraduate years should be devoted to laying really broad foundations—to acquiring the spirit of the methods of more than one science. It is a practical question how much time the student can spare for broadening the basis on which he is to build, when we remember how much work must be done to acquire mastery in even a single science. But I think it will be necessary, in arranging the details of the longer courses in astronomy, to inquire whether it may not be well to prescribe some work in other sciences whose methods are different from its own—in geology, for example, or in logic, formal and otherwise.

I imagine that the foregoing principles are generally accepted. If so, the arrangement of the particular courses designed to carry them out will take but little time.

GRADUATE INSTRUCTION AT THE LICK OBSERVATORY.

It is probably not necessary to give much space to the discussion of the details of courses of graduate instruction at Mount Hamilton. Students who are suitably prepared should be received here—

(*a*) As special students.

(*b*) As candidates for the master's degree (M. A. or M. S.). (A two years' course.)

(*c*) As candidates for the doctor's degree (Ph. D.). (A three years' course.)

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Graduate students at the Lick Observatory are received very much on the footing of assistants. Their theoretical studies are laid out for them and they are expected to prosecute them without any great amount of assistance, but with proper supervision. For their practical work they are assigned as aids to the astronomers in charge of the various instruments. In carrying out their duties as aids they actually perform the very operations which they will have to execute independently at a later day. The 4-inch transit, the 6½-inch equatorial, the alt-azimuth instrument are available for their exclusive use. In order to illustrate the advantages to the student and to the university to be derived from graduate work at Mount Hamilton, I quote below from the annual report of the director of the observatory to the president of the university for the year 1891. In one form or another these paragraphs have appeared in all my annual reports, 1888–1894:

"It is very important that some steps should be taken to make it easy for advanced students to take a special course at the Lick Observatory for the following reasons: The observatory can hardly render a better service to astronomy and to science in general than by receiving students here who have already finished their college courses and who are desirous of perfecting themselves in practical and theoretical astronomy and in astronomical physics (as spectroscopy, photography, photometry, etc.). No institution in the world is better fitted to give such instruction, and there is a special impetus to be gained in an observatory which is regularly pursuing work of discovery and research. The student comes directly into the current and learns far more by observation of the methods of others than by the study of text-books. He can take part in the regular work of the astronomers also.

"The department of mathematics at Berkeley stands ready (1891) to give instruction in the higher branches of mathematical astronomy, and the Lick Observatory is fortunate in counting among its own astronomers several of great experience and ability as teachers. The advantage to the student is obvious. It is a great advantage to the university as a whole to count among its members a considerable number of active and ambitious young men who are able to work with some independence to advance science and not merely to acquire what is already known. They set a standard of scholarship to all the undergraduates. Such students can take a useful part in the actual observations of every day as assistants, and after some practice they become valuable aids in our work of computation and observation and supplement the permanent force of the observatory in an important degree. If a number of such gentlemen can be provided for here it will not be necessary to ask the regents for an increase in the observing force."

RELATION OF A UNIVERSITY OBSERVATORY TO THE TEACHING OF STUDENTS.

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It is clear from what has gone before that the whole time of the observers at Mount Hamilton is needed here in order that the astronomical work expected of them shall be properly done; and that no other serious duties can be laid upon them without materially injuring the scientific efficiency of the establishment.

Should the number of astronomers here be largely increased more time could be spared from the strictly observational work.

At the same time it is unquestionably desirable that the members of the astronomical staff at the Lick Observatory should have some direct connection with the undergraduate students of the university, as I pointed out in 1887. The important point is to bring about this direct connection and at the same time not to interrupt the progress of work at Mount Hamilton. I understand that it is the opinion of [the] committee [of the regents] that this could be satisfactorily accomplished by arranging to have the astronomers of the observatory deliver lectures before the whole university at intervals throughout the academic year. If such lectures are given I think that attendance upon them should be optional on the part of the students. The number and dates of such lectures could be arranged by the president each year.

It appears that it is not advisable to require more than this from the astronomers of the Lick Observatory, because their number is not large and their time is fully occupied; and because their highest use to the university consists, and always will consist, in their work with the instruments of the observatory. The observatory is about to receive another great telescope, and our duties at Mount Hamilton will be materially increased on this account. By leaving the programme of astronomical lectures under the control of the president they can be arranged so as to fulfill all wants at Berkeley and at the same time not to interfere with the work at Mount Hamilton.

The principles formulated in what precedes appear to be of general validity. They are easy of application to any particular case. The section of this chapter which gives the courses of instruction at various American colleges will enable any competent teacher to select the particular courses of study to meet the special demands of his students. These courses are, it must be remembered, the result of long experience, and they have been arranged by teachers of the first rank, many of whom are investigators of distinction.

It is likely that a student intending to devote himself exclusively to astronomy will be able to spend at least three years in graduate work and to take his doctor's degree. It is obvious from an inspection of the foregoing programmes that such a student can find ample opportunities at any one of a number of American colleges, and that it is no longer necessary to go abroad to obtain the highest grade of instruction. On the other hand, each college possesses certain special and peculiar facilities, and each observatory works in a particular direction or line. It is much to the advantage of the student to become more or less familiar with different methods of work and with various instruments. It follows, therefore, that his three years of graduate work should be spent at more than one college when such a course is practicable. If he has passed his undergraduate years of study in one college it will often be desirable for him to select another for the first two years of his graduate course, and to spend the third year at still another, at home or abroad. The advice of his immediate instructors should, of course, always be sought before making a choice; and it should be remembered that it is the influence and guidance of accomplished astronomers and men that is to be sought rather than the mere facilities afforded by great establishments.

The pupils of a Bessel or of an Argelander lived in the midst of the highest intellectual activity and breathed their methods in, as it were, insensibly. The largest instrumental facilities will not make up for the lack of the spirit of research, which is the sole important matter.